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Black Ring Deconstruction*

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Black Ring Deconstruction

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Abstract

We present a sample microstate for a black ring in four and five dimensional language. The microstate consists of a black string microstate with an additional D6-brane. We show that with an appropriate choice of parameters the piece involving the black string microstate falls down a long AdS throat, whose M-theory lift is $AdS_3 \times S^2$. We wrap a spinning dipole M2-brane on the S^2 in the probe approximation. In IIA, this corresponds to a dielectric D2-brane carrying only D0-charge. We conjecture this is the first approximation to a cloud of D0-branes blowing up due to their non-abelian degrees of freedom and the Myers effect.

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1 Introduction

One of the great successes of string theory has been the explanation of black hole entropy in terms of underlying microstates of string solitons [1, 2]. These analyses apply at weak coupling when there is no macroscopic horizon. This picture is somewhat lacking, in that we have no understanding of how a macroscopic horizon can emerge. Recently, a second approach has appeared (see [3, 4] for reviews) where for sufficiently supersymmetric black holes at least some of the microstates can be viewed as a complicated "spacetime foam" [3, 4, 5, 6, 7]. In this picture, the black hole with a macroscopic horizon is the effective semiclassical description of the foam. Using ideas from [8, 9, 10, 11] it was shown in [7] how to connect these two pictures. As the string coupling grows, D-brane bound states grow a transverse size, leading to a topological description as a spacetime foam. A further conjecture was made in [7], namely that every supersymmetric four-dimensional black hole of finite area, perserving 4 supercharges, can be split up into microstates of primitive 1/2-BPS "atoms", each of which preserves 16 supercharges. To describe a bound state, these atoms should have mutually non-local charges.

The 1/2-BPS atoms can be viewed as type IIA branes (generally with worldvolume fluxes turned on) wrapping the internal manifold. A "scaling" solution is present when the charges are chosen such that the corresponding quiver quantum mechanics of open strings on these branes has a closed loop. In [12] it was shown that this scaling causes the branes making up the closed loop to fall down a long AdS throat of constant cross-sectional area. In [7] it was further claimed that the non-Abelian degrees of freedom of each stack of branes will be important in giving the black hole its finite entropy and size. A significant step was taken in this direction in [13], where it was shown that one could add D0-brane charge in the probe approximation by wrapping a dipole D2-brane around a certain S^2 in the non-compact space. It was conjectured that this could be due to the Myers effect causing a cloud of D0-branes to puff up to the dipole D2-brane.

When we lift the four-dimensional IIA solutions to M-theory in five dimensions, there is a greater variety of black objects available to us: strings, holes and rings [14]. The example microstate constructed in [13] was that of a black string in five dimensions. In this short note, we will show that a similar construction can be carried out for a black ring microstate. In four dimensions this becomes the black string microstate with an additional D6-brane (just as a black ring in Taub-Nut becomes a black hole with an additional D6-brane [15]). We find we can indeed add D0-brane charge by wrapping a dipole D2-brane. The quantization of these configurations may dominate the entropy for the corresponding black ring.

In section 2 we review the construction of microstates and the connection between four and five dimensions. In section 3 we give our sample black ring microstate and find a scaling solution. We show that the closed loop part of the configuration falls down a long AdS throat, and the remaining D6-brane remains outside this throat. In section 4 we find a hierarchy of scales inside the throat region and that the metric simplifies in both a "near" and "far" region. In section 5, we show we can wrap a dipole membrane and generate angular momentum in five dimensions which becomes D0-brane charge in four dimensions. We conclude with some discussions and future directions in section 6.

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2 Basics and setup

In this section, we will briefly review our framework for finding microstate solutions. In [5, 6], a general framework was developed for microstate solutions in five non-compact dimensions. In [7] these solutions were extended to four dimensions, with IIA compactified on T^6 give solutions to $\mathcal{N} = 8$ supergravity. In the STU sector, with branes charges dual to the heterotic charges in [16], the general solution can be completely characterized by a symplectic vector of eight harmonic functions on $\mathbf{R}^3$

$$\mathcal{H} = (M_0, M_i, K^0, K^i) = \Gamma_\infty + \sum_p \frac{\Gamma_p}{\rho_p}, \quad i = 1, \ldots, 3, \tag{2.1}$$

where $\rho_p = |\vec{x} - \vec{x}_p|$ for some positions $\vec{x}_p$. $\Gamma_\infty = (\delta M_0, \delta M_i, \delta K^0, \delta K^i)$ is a constant vector, which completely determines the values of the scalars at infinity. It must satisfy:

$$J_4(\Gamma_\infty) = 1, \qquad < \Gamma_\infty, \sum_p \Gamma_p >= 0 \tag{2.2}$$

where J_4 is the quartic invariant of $E_{7(7)}$ applied to our restricted set of charges. For a pair of general vectors of the form $\Gamma_p = (Q_0^p, Q_i^p, Q_p^0, Q_p^i)$ the U-duality invariant symplectic product is defined as (sum on i implied)

$$< \Gamma_p, \Gamma_q >= \frac{1}{2} \left(Q_p^0 Q_0^q - Q_q^0 Q_0^p + Q_p^i Q_i^q - Q_q^i Q_i^p \right). \tag{2.3}$$

Each center represents a D-brane wrapping a cycle in the internal manifold with worldvolume fluxes turned on and quantized charges $(D6, D2_i, D0, D4^i)$ given by Γ_p. Throughout this paper we will take the D2 and D4 charges to be diagonal in the i index, and merely identify them with a 1, e.g. $M_i = M_1, \forall i$.

Using the harmonic function, we can construct several combinations which will appear in our expressions throughout. We define

$$Z = M_1 - \frac{(K^1)^2}{M_0}, \tag{2.4}$$

$$k_0 = \frac{L}{4} K^0 + \frac{L}{2} \frac{(K^1)^3}{M_0^2} - \frac{3L}{4} \frac{M_1 K^1}{M_0}, \tag{2.5}$$

$$J_4 = \frac{L^2}{4} \left(Z^3 H - k_0^2 H^2 \right), \quad H = -\frac{4}{L^2} M_0, \tag{2.6}$$

where L is the radius of the M-theory circle (see [7]), which we will set equal to one from now on along with $8G_N^{(4)} = 1$.

The ten-dimensional (four non-compact) IIA string frame metric and dilaton are given by [1]

$$ds_{10}^2 = -J_4^{-1/2}(dt + k_a dx^a)^2 + J_4^{1/2} \left(ds_{\mathbf{R}^3}^2 + (-ZM_0)^{-1} ds_{T^6}^2 \right), \tag{2.7}$$

$$e^{2\Phi} = (J_4)^{3/2}(-Z^3 M_0^3)^{-1}. \tag{2.8}$$

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[1]There are non-trivial gauge and B-fields in this background as well, we omit them here for brevity's sake. For details we refer the reader to [7].

where $k_a dx^a$ is a one-form that satisfies

$$\star_3 d(k_a dx^a) = < d\mathcal{H}, \mathcal{H} >, \tag{2.9}$$

and the Hodge star operates on the flat $\mathbf{R}^3$ only. There is an integrability condition on $k_a dx^a$, which leads to the bubble equations [7, 5, 6]

$$< \Gamma_p, \Gamma_\infty > + \sum_{q \neq p} \frac{< \Gamma_p, \Gamma_q >}{\rho_{pq}} = 0, \tag{2.10}$$

where $\rho_{pq} = |\vec{x}_p - \vec{x}_q|$. The sum of these equations just reduce to the condition in eq.(2.2). Note also that the asymptotic volume of T^6 is proportional to $(-ZM_0)^3$. There are two possible conventions here: one can either normalize T^6 to unit volume and let the asymptotic value of $(-ZM_0)$ determine its volume, or one can restrict the choice of Γ_∞ further such that this expression asymptotes to one and let T^6 have arbitrary volume. We choose the latter convention, with the additional convenient choice of all equal size T^2's.

When we lift our ten-dimensional metric to M-theory we obtain

$$\begin{align}
ds_{11}^2 &= -Z^{-2}(dt + k_0\sigma + k_a dx^a)^2 + Z\, ds_{HK}^2 + ds_{T^6}^2, \tag{2.11}\\
ds_{HK}^2 &= H^{-1}\sigma^2 + H(dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2) = H^{-1}\sigma^2 + H d\tilde{s}_{\mathbf{R}^3}^3, \tag{2.12}
\end{align}$$

where $r = \frac{L\rho}{2} = \rho/2$. The one-form $\sigma = d\tau + f_a dx^a$ is defined by $d\sigma = \star_3 dH$. Note that if $\lim_{r\to\infty} k_0 = \frac{1}{2}\tan\alpha\sec\alpha \neq 0$, i.e. if the total central charge of our solution has a non-zero phase α, our lift puts the M-theory metric in the somewhat unorthodox form where ∂_t and ∂_τ are no longer orthogonal at infinity (see [15] for a similar discussion). For $\alpha \to \pm\pi/2$, the asymptotic metric goes to $\mp dt\,\sigma + \frac{1}{4}\sigma^2 + 4r^2 ds_{\mathbb{S}^2}^2$; the vector ∂_t becomes null as it does for all the other zeros of H at finite r.

3 A sample black ring microstate

In this section, we will construct an example that represents the semiclassical limit of a black ring microstate. In [13] a sample microstate for a D4-D0 black hole was found. When lifted to five dimensions, this solution becomes a wrapped black string. To get to a black ring microstate we add a single (pure) D6-brane that is separated by a parametrically large distance from the initial branes in [13]. The addition of the D6-brane means that the M-theory circle that the would-be black string (whose microstate this is) wraps is now contractible, turning this solution into a black ring microstate where the radius of the ring is proportional to the distance to the added D6-brane. If this distance were to become parametrically small, the extra pole becomes part of our "fuzzball" and our solution would be a black hole microstate. All solutions lift to mostly smooth solutions in eleven dimensions characterized by a "foam" of two-cycles [5, 6] with a shock-wave from the D0-branes.

We begin by placing the initial branes. The D6 and $\bar{\text{D}}6$-branes carry worldvolume flux which induces the other brane charges. They can be written

$$\Gamma_1 = \frac{1}{2}(-1, -m^2, m^3, m), \quad \Gamma_2 = \frac{1}{2}(1, m^2, m^3, m). \tag{3.1}$$
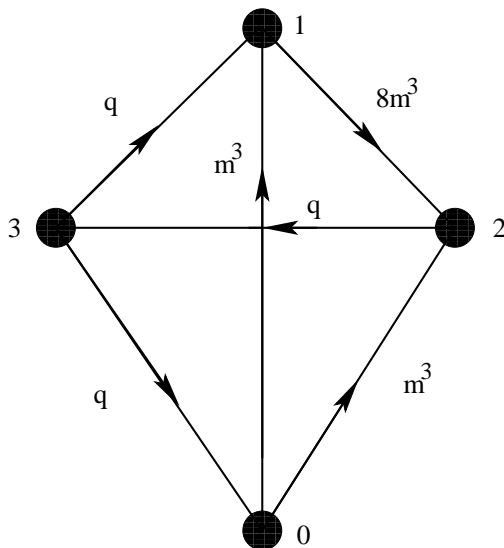
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Figure 1: The quiver for the black ring microstate example.

We also add q D0-branes with total charge vector

$$\Gamma_3 = \frac{q}{2}(0, 0, -1, 0). \tag{3.2}$$

Lastly, we add a single, pure D6-brane with charge vector

$$\Gamma_0 = \frac{1}{2}(-1, 0, 0, 0). \tag{3.3}$$

In [5] it was shown how to construct a quiver model for the corresponding open string quantum mechanics living on these branes, Fig. 1 displays the quiver for this setup, the numbers on the diagonals are the intersection numbers $\gamma_{pq} = <\Gamma_p, \Gamma_q> /G_N^{(4)}$. Note that each node is associated with a $U(1)$ gauge group, except the third note which has gauge group $U(q)$ and thus non-Abelian degrees of freedom.

It was also shown in [7, 11] that whenever a given quiver has a closed loop, so long as the corresponding intersection numbers satisfy triangle inequalities, we can find a "scaling" solution for that part of the quiver. These scaling solutions allow the distance between the corresponding branes *in the flat* $\mathbf{R}^3$ base to be taken arbitrarily small. In the full metric, instead we develop a longer and longer throat region which is smoothly capped. The cross-sectional area of this cap remains constant as the throat deepens [12]. Looking at the quiver, we can see there are two possible closed loops, 1-2-3 and 2-3-0. We will analyze the 1-2-3 closed loop here, the 2-3-0 case can be solved in a similar manner.

Grouping terms suggestively, the bubble equations become (letting the positions of the

individual D0-branes be labelled $\vec{x}_{3_i}$)

$$\left(< \Gamma_1, \Gamma_\infty > - \frac{m^3}{8\rho_{10}} \right) \quad + \quad \left(\frac{m^3}{\rho_{12}} - \sum_{i=1}^{q} \frac{1}{8\rho_{13_i}} \right) = 0, \qquad \textit{bubble1} \qquad (3.4)$$

$$\left(< \Gamma_2, \Gamma_\infty > - \frac{m^3}{8\rho_{20}} \right) \quad + \quad \left(-\frac{m^3}{\rho_{12}} + \sum_{i=1}^{q} \frac{1}{8\rho_{23_i}} \right) = 0, \qquad \textit{bubble2} \qquad (3.5)$$

$$\left(< \frac{\Gamma_3}{q}, \Gamma_\infty > + \frac{1}{8\rho_{03_i}} \right) \quad + \quad \left(\frac{1}{8\rho_{13_i}} - \frac{1}{8\rho_{23_i}} \right) = 0, \quad \forall i = 1, \ldots, q. \qquad \textit{bubble3} \qquad (3.6)$$

We are seeking a solution where $\rho_{10}, \rho_{20}, \rho_{03_i} \to \rho_0 \gg \rho_{12}, \rho_{13_i}, \rho_{23_i} \to 0$. That is, in each of the bubble equations, the terms in the second set of parentheses will dominate while the first term drops out just as the constant terms were ignored in such equations for the black string microstate in [13]. The last equation (3.6) tells us that each D0-brane must be equidistant between the D6 and $\bar{\text{D}}$6-brane, $\rho_{13_i} = \rho_{23_i}$, so the D0-branes lie on a plane between them. Using this in (3.4) we find that the separation of the D6 and $\bar{\text{D}}$6 pair is

$$\rho_{12} = 8m^3 \left(\sum_{i=1}^{q} \frac{1}{\rho_{13_i}} \right)^{-1} \equiv 2R_6. \qquad (3.7)$$

We still need to make sure the triangle inequalities are satisfied for this to be a solution. The distance from any D0-brane to either D6-brane in the pair is at least R_6, so to satisfy the triangle inequalities we require

$$q \geq 4m^3. \qquad (3.8)$$

When this is satisfied we have a scaling solution. It is interesting to note that this is different from, but implies, the condition for $J_4(\Gamma_1 + \Gamma_2 + \Gamma_3) \geq 0$ which is $q \geq 2m^3$. In this case, the branes making up the closed loop part of the quiver fall down a long AdS throat, with the remaining D6-brane left outside. Fig. 2 shows a rough sketch of this.

We can determine an effective $\mathbf{R}^3$ distance from the pure D6-brane to the other three D-branes (the real geodesic distance scales to infinity as we bring those last three poles together) by aggregating these three in $\Gamma_R = \Gamma_1 + \Gamma_2 + \Gamma_3$ and using a simple two-pole constraint equation (we restore $G_N^{(4)}, L$ here):

$$\rho_0 \approx -\frac{< \Gamma_0, \Gamma_R >}{< \Gamma_0, \Gamma_\infty >} = \frac{4G_N^{(4)} (q - 2m^3)}{L \, \delta K^0}. \qquad (3.9)$$

This number only makes physical sense if the asymptotic moduli are such that $\delta K^0 > 0$, otherwise the SUSY solution disappears . In the scaling limit, ρ_0 is by definition much larger than the decoupled scales ρ_{12}, ρ_{13} and ρ_{23}. Thus we have the beginnings of a nice hierarchy of scales.

4 Extending the hierarchy of scales

We have seen that we can find a scaling solution for a black ring microstate, in which the D6-$\bar{\text{D}}$6-D0 branes fall down a long throat, and a single D6-brane remains outside. If we focus
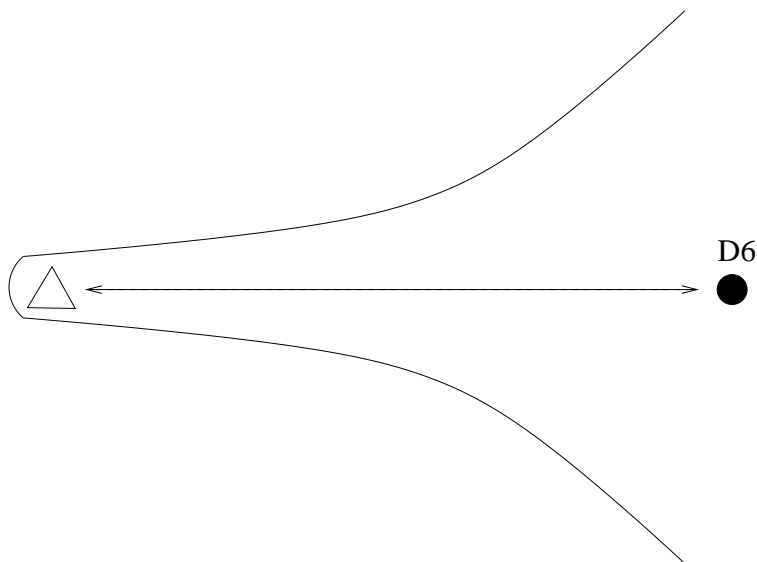
Figure 2: Rough sketch of the closed loop of the quiver falling down a throat in the scaling solution with a single D6-brane left outside.

on the region down the throat (the closed loop part of the quiver), then this case becomes the black string case of [13]. We can take $q \gg 4m^3$, in which case the D6-branes will typically be much closer to the plane containing the D0-branes, than to any of the D0-branes themselves. As a simple example, we can let all of the D0-branes lie in a ring of radius R_0. We then find

$$R_6 = \frac{4m^3}{q}\sqrt{R_6^2 + R_0^2} \ll R_0. \qquad (4.1)$$

As in [13] we find that the metric simplifies in both a far region, $\rho_0 \gg |\vec{x}| \gg R_0$ and a near region $|\vec{x}| \ll R_0$. In the far region, the metric simply becomes that of the near horizon of a D4-D0 black hole, whose lift is

$$ds_5^2 \approx \frac{(q - 2m^3)}{8m}d\tau^2 - \frac{2r}{m}d\tau dt + m^2\left(\frac{dr^2}{r^2} + d\eta^2 + \sin^2 \eta d\psi^2\right). \qquad (4.2)$$

In the near region, we can change to prolate spheroidal coordinates

$$\rho_1 = R_6(\cosh \beta + \cos \eta), \quad \rho_2 = R_6(\cosh \beta - \cos \eta), \qquad (4.3)$$

and further make the coordinate transformations

$$t = \frac{2m^3}{R_6}x, \quad \tau = 2(x + \theta), \quad \phi = \psi + x - \theta, \qquad (4.4)$$

to obtain

$$ds_5^2 \approx m^2(d\eta^2 + \sin^2 \eta d\psi^2) + 4m^2\left(-\cosh^2(\frac{\beta}{2})dx^2 + \sinh^2(\frac{\beta}{2})d\theta^2 + \frac{1}{4}d\beta^2\right), \qquad (4.5)$$

which is global $AdS_3 \times S^2$. Note that we have regular 2π identifications on θ and ψ.

Let us step back a moment and review what we have done. We started with a solution for a black ring microstate that consisted of two pieces, a cloud of D6-$\bar{\text{D}}$6-D0 branes and a single pure D6-brane separated from the cloud. We found that there was a scaling solution, where the cloud of branes fell down a long throat, leaving the single D6-brane outside. We then focused in on the cloud of branes down the throat and found this case to be that of the black string microstate analyzed in [13]. In particular, if we take $q \gg 4m^3$, we find that the ring of D0-branes is much further from the pair of D6-branes than the D6-branes are from themselves, which allows us to focus in further on both a near and far limit. Hence, we should be able to "deconstruct" the black ring in a similar way to that of the black string.

5   Wrapped branes and deconstructing the ring

In this section, we show that in the probe approximation, we can add a dipole M2-brane that wraps the S^2 that appears down the throat and in the near limit. Because the cycle it wraps is in a contractible class at infinity, it cannot carry any net M2 charge. This dipole brane does carry angular momentum around a circular direction in the AdS_3, which when reduced along τ leads to a D0-brane charge. We conjecture that this is a result of the Myers effect on a cloud of D0-branes when brought near the pair of D6-branes, where gradients of both the dilaton and RR one-form play a role.

In [13] it was shown for the black string case that in the near limit one can wrap a supersymmetric M2-brane on the S^2 of (4.5), sitting at constant $\beta = \beta_0$ and $\tau = \tau_0$ (and hence moving in $\theta = \tau_0/2 - x$). This is an ellipsoidal brane with the D6-$\bar{\text{D}}$6 pair acting as the foci for the ellipsoid. We will wrap our M2-brane in the same way for the black ring case. It was further claimed that this configuration would be BPS in the full geometry since in the black string case in both the near limit and the full geometry the base space depends only on M_0, which is the same for both (for convenience the constant term in M_0 was set to zero, i.e α was set to $\pm\pi/2$). Here, there is a further subtlety, since in the full geometry, M_0 includes the added pure D6-brane. However, we do not anticipate a large change because the probe brane is being added very far down the throat and in the probe approximation.

One can readily calculate the angular momentum around the θ circle (we use $\tau_{M2} = 1/(4\pi^2 l_p^3)$ and return other dimensionful factors) contributed by the M2-brane

$$J_\theta = -\frac{2m^3}{\pi} \frac{(2\pi l_p)^6}{V_{T^6}} \sinh^2(\frac{\beta_0}{2}). \tag{5.1}$$

While this will correspond to adding positive D0-brane charge upon reduction, it reduces the net J_R of our solution. This reduction typically increases the entropy of SUSY black objects in five dimensions, so adding wrapped objects like this M2 seems like an efficient way to provide new solutions for microstates of finite entropy black objects in five dimensions.

We wish to reduce this setup to get a IIA solution. One subtlety that arises is precisely which circle to reduce on, along ∂_θ or $2\partial_\tau$? While the Killing vector ∂_θ appears to be the natural choice in the near metric, in the full geometry the reduction is along $2\partial_\tau$, and it is thus this circle that we should use to appropriately define our charges. One might well

ask how a reduction along $2\partial_\tau$ produces any D0-brane charge in four dimensions, since the M2-brane position is independent of τ. The answer is that the τ-circle both varies in size and is non-trivially fibered over the S^2 that the M2-brane wraps; these two features each contribute to the $U(1)$ field strength F on the D2-brane (see [17] for more details on the reduction). Dualizing the appropriate vielbein in the usual way gives us the worldvolume field on the D2-brane

$$\mathcal{F} = F = \frac{m^3}{\pi}\sin\eta\left(\sinh^2(\frac{\beta_0}{2})d\eta \wedge d\varphi - d\eta \wedge dx\right)\left(\frac{(2\pi l_p)^6}{V_{T^6}}\right), \qquad (5.2)$$

where $\varphi = \frac{\tau}{2} - x$. This dipole D2-brane carries only net quantized D0-charge

$$n_{D0} = -J_\theta, \qquad (5.3)$$

and no other charges, in particular one can see that the fundamental string charge vanishes because of the simple topological fact that the M2-brane is not wrapping the τ direction. To get the physical D0-charge (i.e. to establish the D0-brane tension) we need a value for g_s, set by the radius of compactification. In the region near our closed quiver, in both the near and far limit, we are operating in a decoupling regime which has "forgotten" any scale relating to the size of the τ circle: there is no set value we can use. In the full geometry, one could choose as a reference scale the separation from the naked D6 brane in (3.9) or the asymptotic size of the M-circle L.

Finally, as in [13], these branes move on the T^6 as particles in a magnetic field due to the C and B-fields with legs on the torus. It seems possible to add D0-brane charge to a microstate by using these wrapped branes, which could be interpreted as a cloud of D0-branes blown up by the Myers effect. However, we caution that this calculation was done in the probe approximation. It would be interesting to attempt to take into account the backreaction.

6   Discussion

In this note we have presented an example of a black ring microstate and shown that a picture emerges of a cloud of branes falling down a long AdS throat, and a single brane remaining outside. In the throat region one can take a near and far limit. In the near limit the D0-branes are distant actors whose only role is to set the overall AdS scale. We then showed that we can add some more D0-brane charge back by wrapping a dipole D2-brane and conjectured that the complete cloud of D0-branes would blow-up into such a dipole brane via the Myers effect, much like giant gravitons. It would be interesting to explore detailed aspects of this phenomenon.

To nail down the physics of microstates in detail we will need to go beyond the assumptions in this paper. Our construction of the wrapped brane was done in the probe limit, and only in the near region. In particular, it is not clear to us why a dipole brane carrying all the D0 charge would have such a uniform charge density on S^2 so unlike the original charge density of the D0-brane ring confined to the equatorial plane of S^2. It would be useful to see

how the dielectric construction carries over when the backreaction of the charged D2-brane is taken into account. In the M-theory picture perhaps more general pseudo-Hyper-Kahler spaces will appear (see [18] for some examples of such). Additionally, can we actually see a cloud of D0-branes puffing up by using their non-Abelian degrees of freedom? One might have expected a ring of D0-branes to blow up into more of a torus than a sphere. In general, we feel that it will be essential to understand how these di-electric effects act on component branes to fully understand how much of the entropy a black object is accounted for by the scaling solutions containing a small number of nodes. Do these small quivers dominate the ensemble for the corresponding black object?

Finally, the closed loop in our example and that of [13] has several particular properties which may not persist for more general closed triples of nodes. First, one of the nodes, the D0-branes, has zero intersection number with the sum over the other two. It would be interesting to understand what happens if were to add a little extra D2-charge to this node: a dielectric D4-brane perhaps? Second, only two of the nodes in the closed loop are primitive, they cannot be split into smaller integer quantized stacks and so have no non-Abelian degrees of freedom. With all three nodes non-primitive, could we have multiple and simultaneous dielectric effects? Again, the question arises as to how generic our example is. It certainly cannot be a microstate for its "parent" black object if $2m^3 > Q^0 = (q - 2m^3) > 0$. To get a full picture of what are typical microstates and what dominates the entropy of black objects, we either need to extend our basic picture to a more general class of quivers, or understand why these other candidates don't contribute in a substantial way to the entropy of the ensemble.

These and other issues present challenging problems, but solving them is important for our understanding of black objects, the information puzzle and how classical spacetimes emerge from underlying quantum mechanical states.

Acknowledgements

References

[1] A. Sen, "Extremal black holes and elementary string states," *Mod. Phys. Lett.* **A10** (1995) 2081–2094, `hep-th/9504147`.

[2] A. Strominger and C. Vafa, "Microscopic origin of the bekenstein-hawking entropy," *Phys. Lett.* **B379** (1996) 99–104, `hep-th/9601029`.

[3] S. D. Mathur, "The fuzzball proposal for black holes: An elementary review," `hep-th/0502050`.

[4] S. D. Mathur, "The quantum structure of black holes," `hep-th/0510180`.

[5] P. Berglund, E. G. Gimon, and T. S. Levi, "Supergravity microstates for bps black holes and black rings," `hep-th/0505167`.

[6] I. Bena and N. P. Warner, "Bubbling supertubes and foaming black holes," `hep-th/0505166`.

[7] V. Balasubramanian, E. G. Gimon, and T. S. Levi, "Four dimensional black hole microstates: From d-branes to spacetime foam," `hep-th/0606118`.

[8] F. Denef, "Supergravity flows and d-brane stability," *JHEP* **08** (2000) 050, `hep-th/0005049`.

[9] F. Denef, B. R. Greene, and M. Raugas, "Split attractor flows and the spectrum of bps d-branes on the quintic," *JHEP* **05** (2001) 012, `hep-th/0101135`.

[10] B. Bates and F. Denef, "Exact solutions for supersymmetric stationary black hole composites," `hep-th/0304094`.

[11] F. Denef, "Quantum quivers and hall/hole halos," *JHEP* **10** (2002) 023, `hep-th/0206072`.

[12] I. Bena, C.-W. Wang, and N. P. Warner, "Mergers and typical black hole microstates," *JHEP* **11** (2006) 042, `hep-th/0608217`.

[13] F. Denef, D. Gaiotto, A. Strominger, D. Van den Bleeken, and X. Yin, "Black hole deconstruction," `hep-th/0703252`.

[14] R. Emparan and H. S. Reall, "A rotating black ring in five dimensions," *Phys. Rev. Lett.* **88** (2002) 101101, `hep-th/0110260`.

[15] H. Elvang, R. Emparan, D. Mateos, and H. S. Reall, "Supersymmetric 4d rotating black holes from 5d black rings," `hep-th/0504125`.

[16] M. J. Duff, J. T. Liu, and J. Rahmfeld, "Four-dimensional string-string-string triality," *Nucl. Phys.* **B459** (1996) 125–159, `hep-th/9508094`.

[17] E. Bergshoeff and P. K. Townsend, "Super d-branes," *Nucl. Phys.* **B490** (1997) 145–162, `hep-th/9611173`.

[18] I. Bena, N. Bobev, and N. P. Warner, "Bubbles on manifolds with a u(1) isometry," `arXiv:0705.3641 [hep-th]`.